Chapter

Face Mask: A Novel Material for Protection against Bacteria/Virus

Thilagavathi Govindharajan and Viju Subramoniapllai

Abstract

Facemask is defined as a loose-fitting device which creates a physical barrier between the mouth and nose of the individual wearing mask and likely pollutants in the immediate environment. Evolution of severe viral respiratory infectious agents such as pandemic COVID-19, severe acute respiratory syndrome, pandemic influenza and avian influenza has driven the use of protective face masks by public and health workers. In this chapter, characteristics features and uses of different types of masks are discussed. Characteristics of various nonwoven technologies for manufacturing face masks are also discussed. Test methods and recent developments in face masks are briefly covered.

Keywords: Face Mask, Bacteria, Virus, Filtration

1. Introduction

Facemasks are in general used for reducing breathing exposure to airborne particles such as virus and bacteria that may be connected with a wide range of health effects [1]. Facemasks are considered to impede or reduce the spread of airborne particles that causes annoying health issues. Facemask is defined as a loose-fitting device which creates a physical barrier between the mouth and nose of the individual wearing mask and likely pollutants in the immediate environment [1]. Based on the use, face mask is commonly characterized as medical, isolation, dental and surgical masks. Usually a face mask is made-up of flat or pleated fabric with one to three layers, which in turn secured to the head with ear loops [1, 2]. An evolution of severe viral respiratory infectious agents such as pandemic COVID-19, severe acute respiratory syndrome, pandemic influenza and avian influenza has driven the use of protective face masks among public and health workers [3].

The face masks worn must prevent the infectious microbes such as viruses and bacteria from penetrating through the fabric structure. Hence it is recommended to produce fabric structures with pore sizes lesser than the microbe size. If the size of the microbes is known, then the fabrics can be manufactured according to the requirements. **Tables 1** and **2** shows the specific viruses and bacteria and associated diseases. From **Tables 1** and **2**, fabric producers can get an idea regarding the pore size required in face masks for filtering viruses and bacteria respectively [4]. This chapter discusses the different types of face masks, filtration mechanisms, manufacture and characteristic features of various face masks. Test methods and recent developments in face masks are also covered.

Species	Size (mm)	Associated diseases
Hepatitis Virus	0.042–0.047 diameter	Hepatitis B
Adenovirus	0.07–0.09 diameter	Respiratory Infections
HIV	0.08–0.11 diameter	Acquired Immuno Deficiency Syndrome
Filoviruses	0.08 diameter	Ebola Virus
Bunyaviridae	0.08–0.12 diameter	Hanta Virus
Orthomyxoviridae	0.08–0.12 diameter	Influenza A, B, and C
Coronaviridae (SARS)	0.10–0.12 diameter	SARS
Varicella-Zoster Virus	0.11–0.12 diameter	Herpes
Cytomegalovirus	0.12–0.20 diameter	Pneumonia, Hepatitis, Retinitis

Table 1.
Size of some highly infectious disease viruses [4].

Species	Size (mm)	Associated diseases
Serratia marcescens	0.45 diameter	Extra-intestinal Infections, Nosocomial Infections
Pseudomonas aeruginosa	0.50–1.0 diameter	Endocarditis, Pneumonia, Osteomyelitis, Nosocomial Infections, Meningitis, Septicemia
Staphylococcus aureus	1.0 diameter	Pneumonia, Osteomyelitis, Pneumonia, Osteomyelitis
Mycobacterium tuberculosis	1.0–5.0 diameter	Tuberculosis
Bacillus anthracis	1.0–1.5 diameter	Anthrax Infection

Table 2.
Size of some disease-causing bacteria [4].

2. Different types of masks

Masks are fabricated based on the size of pores and particles desired to be filtered out, which is mainly determined by the health and medical professionals. Different types of masks as per the characteristics features and specific uses are discussed below.

2.1 Dust mask

Dust masks are in general flexible and these masks are developed to provide protect against dust, molds, pollens and other irritants. They normally not provide protection against any pathogens and therefore they should not be used for viral protection [3].

2.2 Single-use face mask

Single-use face masks are disposable and commonly used for single application. They are usually made from wood pulp tissue paper or single layer nonwoven fabric and are very thin. They are normally used for providing protection against larger dust particles, at construction sites and in other similar industries. It is not recommended to use such type of face masks for protection against covid-19 [3].

2.3 Surgical mask

Surgical mask is defined as a loose-fitting and disposable device that creates a physical barrier between mouth and nose of the wearer and the probable pollutants in the immediate environment [3]. Surgical mask is normally composed of 3 layers. The innermost layer contains an absorbent material which absorbs moisture while the wearer is breathing. The middle layer is made of melt blown nonwoven which work as a filter, and the outer layer repels liquids [5]. The surgical mask prevents the splashes, larger-particle droplets or sprays with a diameter above 100 mm. It also controls the spread of respiratory secretion and a person's saliva to others. The Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2 virus) is spherical, though slightly pleomorphic, has a diameter of 60–140 nm. These masks will not be able to prevent inhalation of very small particles existing in the air and therefore it does not offer full protection against pathogens [3].

2.4 N95 respirator

*N95 respirator*s are normally non-oil resistant and also termed as electrets filter. The word N95 denotes that these types of face masks can filter at least 95% of aerosols at particle size 0.3 μm [6, 7]. It is reported N95 respirators sometimes do not offer adequate protection against the aerosol particles which are lesser than 300 nm. Hence protection given by certain N95 respirator masks can also drop below 95%, during high inhalation flow rates [6]. The N95 respirators of different industries has varied performance mainly based on the penetrating particle's size. The N95 respirator is made up of four main layers namely inner layer, support layer, filter layer, and layer mask filter layer from inside to outside of it. In addition, a ventilator fan is mounted on the outer layer of N95 to enhance the breathing performance. N95, N99 and N100 masks filter the corona virus effectively [6]. International regulation suggests that the surgical masks and N95 respirator are not advisable to be worn continuously for more than 4 hours and 8 hours respectively, if not it becomes soiled, damaged or contaminated.

2.5 P100 respirator

This is a sort of filtering face piece respirator. It is highly oil-proof and the filtration efficiency of the aerosol particles is 99.97%. From the comparisons made by the researchers regarding the filtration efficiency of N95 and P100 respirators, it was found that there was no considerable gap present in the permeability values before use. Whereas results after post exercise were more expedient for the P100 respirator, on the other hand, N95 failed the post-exercise criterion [6]. Moreover, owing to the likely effects on the breathing resistance, face seal, and moisture retention during the use and hard work, there is the threat of reshaping the face mask. P100 face masks could able to maintain their shape in humid and high temperature compared to the N95 [8].

2.6 Full face respirator

Full-face respirators are constructed using rigid plastic material which consists of both apparent part and central port part [9]. Such masks are used for the management of breathing problems and sleep troubles by providing respiration to patients [6]. Face covering part is made from flexible elastomeric material that fits well to cover the anatomy of face. Due to the elastic nature, straps aids in generating adequate force which gives good adherence of mask on to the wearer's face.

However, this arrangement not works well if the person rolls during sleep. In such situations, masks are removed from the wearer, which disconnects the sealing between mask and face of the wearer and thus leads to poor protection [10].

3. Mechanisms of filtration

The filtration mechanism of filter fabrics is mainly based on physical filtration mechanism namely interception, inertial impact, diffusion, gravitation, and electrostatic attraction [4]. During a particle filtration process, an interception takes place as the particle radius is equal to or greater than the fiber-particle distance (within 0.1 to 1 μm particle size) [4]. The particles are instantly arrested outside the face masks as soon as it comes in contact with and attaches to the fiber following the air streamline around the fiber. Inertia impact occurs when a particle size is bigger than 1 μm with a larger mass, which are not capable of going after the arc pathway of the air streamline crashes into the fiber. For the particles in high velocity, it becomes harder to penetrate through the pores of the mask sieve and to arrive at wearer. The diffusion mechanism [2, 3] makes the particles to diverge from the actual flow lines arbitrarily when they are close to fibers, mainly for particles sizes which are lesser than 0.1 μm. In the filter fabrics the electrostatic attraction occurs through the electrostatically charged mats [3]. By means of electrostatic driven adsorption the oppositely charged particles are attracted. The electrostatic attraction is efficient for capturing sub-micron particles with no increase in pressure drop [3]. On the other hand, the filtration state will alter when the fibers of the filter fabrics are within nanoscale. By means of charging techniques namely corona charging, tribocharging, and electrospinning the aerodynamic behavior of airflow around the filter can be made [4]. Nevertheless, the charges will decompose steadily during use or long-term storage.

4. Polymeric materials used in face masks

Fibers are the tiniest component of a textile structure and their characteristic features are mainly dependent on their physical and chemical properties. Fibers with irregular surfaces/irregular cross-sections have the capability to trap particles efficiently than the fibers with smooth surface/regular cross-sections. Cotton is characterized by convolutions, ideal for capturing small particles. Viscose rayon fibers have striations, which offer certain irregularity to the fibers surface. However, these striations are not as effective in inhibiting particle movements as in cotton fibers. Synthetic fibers such as polypropylene, polyester and nylon intrinsically possess smooth surface structure and round cross-sections that permit particles to certainly slide by the fiber. The smooth and round cross-section also creates capillary forces between fibers. Synthetic fibers with different and irregular cross-sections can be manufactured by using suitable spinnerets during fiber manufacture process and irregularity in the fiber structure can be made by means of texturisation process. Polyester fibers with longitudinal channels possess good wicking property. Fiber length is another factor influencing the fabric barrier properties. Longer fibers are not much effective in capturing small particles than shorter fibers [10].

Commonly used materials for face masks applications includes polypropylene, polyesters, polyamides polyphenylene oxide and polycarbonates. Trifluorochloroethylene is a kind of fluorinated polymers is also used for face mask applications. In general, hydrophobic and thermoplastic polymers are preferred. One of the main advantage of using polypropylene fiber in face mask is its nonabsorbent properties. Antibacterial face mask has been prepared from polypropylene by treating it with dimethyl-dioctadecyl-ammonium bromide. The face mask showed good resistance against bacteria [6]. Madsen et al. [11] analyzed the filtration efficacy of face masks made from polypropylene, polyester, glass fiber and cellulose material. The polypropylene showed highest filtration efficiency followed by polyester, glass and cellulose material. The filtration efficiencies of several commonly available fabrics from silk, cotton, flannel, chiffon, and synthetic fibers has been evaluated by Konda et al. [12]. It is observed that for particle sizes of <300 nm, the filtration efficiencies ranged from 5–80% whereas, for particle sizes >300 nm, filtration efficiencies ranged from 5–95%. It is also noted that the face mask produced from cotton-flannel, cotton-chiffon and cotton-silk showed more than 80% filtration efficiency for particle size less than 300 nm and also showed 90% filtration efficiency for particle size greater than 300 nm. Recently, micro fibers and nanofibers are gaining greater attention due to its unique features.

5. Technology of Manufacturing Face mask

The filtration efficiency of a face mask depends on several factors including fiber type, fiber's cross-sectional shape, technology of manufacture and web's structure. There are several methods to develop fibrous matt that can be used as filters in masks. Face masks are generally prepared from nonwoven fabrics as nonwoven fabrics offers superior filtration efficiencies than woven or knitted fabrics owing to their randomness and 3D structure which permits higher thickness which increases the particle travel distance. Layered nonwoven structures can also be used for the development of face masks. The key nonwoven technology for manufacturing face masks includes melt blown, spun bonding and electrospinning [3]. **Table 3** shows the characteristics of various nonwoven technologies for manufacturing face masks [3].

Factors	Melt blowing	Spun bonding	Electrospinning
Extrusion	A high-velocity air propels a molten thermoplastic resin from extruder	Rotating screw obliges the melt to extrude	The charged polymer jet is extruded via nozzle and drawn with the help of applied electrostatic force
Bonding	Self-bonding of fibrous web in the air.	Bonding by means of mechanical, chemical or thermal method	Thermal bonding used as a post-processing treatment can enhance the strength of fibers.
Die	Hot air converges with the fiber as it come out from the die	Hot air flow is at a cross flow to the out coming fiber	Positive charge is applied at extruder.
Fiber diameter	Ranges from 1 to 5 μm	Ranges from 15 to 50 μm	Ranges from 100 nm to 500 nm
Applications	Surgical face masks, gas filtration, liquid filtration, cartridge filters and clean room filters	Hygiene and healthcare textiles, disposable diapers, automotive industry, filtration, civil engineering, carpet backings packaging.	Tissue engineering, wound dressing, drug delivery and cosmetics, protective clothing, filters and smart textiles

Table 3.
Characteristics of various nonwoven technologies for manufacturing face masks [3].

5.1 Melt blown technology

In this technique, a high-velocity air blows a molten thermoplastic polymer from an extruder die with hundreds of tiny nozzles onto a conveyor or take-up screen to structure a fine fibrous and self-bonded web. The fibers produced via such method have relatively small diameters (1–5 mm) and thus, the pore size is much smaller, this makes them superior in filtration performance [13]. Hence, this technology is mostly used for the development of nonwoven fabrics for various filtration applications such as respirators, surgical face masks, liquid filters, cartridge filters and clean room filters. By introducing electrostatic charges and superabsorbent polymer in melt blown polymer fibers it is possible to improve the particle capturing efficiency, air moisture absorption capability and hygienic comfort [3].

Electrostatic-assisted melt blown fabric has been developed by applying electrostatic field directly to the meltblown spinning head [14]. The mean pore diameter of polypropylene microfibers formed using this technique reduced from 1.69 to 0.96 mm, this also resulted in a narrow fiber size distribution. The mean average pore size of conventional melt blown and electrostatic-assisted melt blown fabric were 33.415 mm and 29.285 mm, respectively [14]. The application of electrostatic force resulted in decreased pore size and mean fiber diameter for electrostatic-assisted melt blown fabric. It is also observed that electrostatic-assisted melt blown fabric had better filtration efficiency than conventional meltblown fabric [14]. For 0.3 mm particle size, the filtration efficiencies of conventional melt blown fabric and electrostatic-assisted melt blown fabric were 40.65% and 50.82%, respectively. Also, for 1 mm particle size, the filtration efficiencies were 73.98% and 86.44% and for 2.5 mm particle sizes, the filtration efficiencies were 95.35% and 98.96%, respectively [3, 14]. With reduced fiber diameter, the pore size also reduces and the even distribution of fibers per unit area increases this gives the particles additional chance to adhere to the nonwoven fabric [3]. Furthermore, electrostatic-assisted melt blown fabric shows good adsorption ability than conventional fabrics. Melt blown technology has also been used to develop N95 respirator mask filters and surgical mask filters. The melt blown fabrics are the most important filter of face masks that arrests the bacteria as well as microbes from entering or exiting the mask. Polypropylene is the most widely used material to produce surgical face mask. The porosity ranges from 75 to 95% and the basis weight of polypropylene web is around 5–1000 g/m^2. Polycarbonate, polystyrene, polyethylene, or polyester compositions are also used to prepare face masks [3].

5.2 Spun bonding technology

In this process, molten polymer is extruded onto a conveyor belt via spinneret. Extrusion is a process where the polymeric chips are generally fed into an extruder containing a rotating screw in a heated barrel in which polymer chips are mixed, then melted and finally pumped through a die, that gives the fibers a uniform thin profile and can also endure higher temperatures. Prepared fibers are then quenched by a cool air, and are collected on a conveyor belt and then are additionally bonded by means of thermal, mechanical or chemical means to form the spun bonded nonwoven fabric. The developed spun bonded fabric have random fibrous structure with a weight ranging from 5 to 800 g/m2, the thickness of the web range from 0.1 to 4.0 mm, and the diameter of the fiber vary from 1 to 50 mm [15]. When the fiber diameter decreases, the pore size of the nonwoven fabric decreases; resulting in more even allotment of fibers which increases the particle capturing efficacy. Polymers such as polyester, polypropylene, polyethylene, nylon, polyurethane, etc. are appropriate polymers for the spun bonding process [16]. Among different polymers, isotactic polypropylene is one of the most extensively used polymer for spunbonded nonwoven fabric manufacture as polypropylene is relatively economical and offers the highest yield (fiber per kilogram). The polypropylene based nonwoven products offers lowest density [3].

5.3 Electro spinning

Electro spinning is a method wherein a polymer based solution is discharged with the help of electric field. The polymeric fluid becomes finer as it passes through the electromagnetic field and deposits on a plate ensuing the production of nonwoven nano-fibrous web. The negative charge is supplied at the collector and positive charge is supplied at the nozzle making the fluid jet to acquire charge at the nozzle tip for the creation of Taylor cone. Charged polymeric fluid is extruded through the nozzle and are drawn by the electrostatic force [17]. As the jet speed up and thins in the electrical field, radial charge repulsion results in splitting the primary jet into numerous filaments, known as "splaying', thereby manufacturing polymeric nanofibers which are electrically charged which are collected at the collector. By means of the subsidiary jets formed, the mean fiber diameter is determined which ranges from 100 nm to 500 nm and the structure and properties of nanofibers is mainly affected by electrostatic forces and viscoelastic behavior of the polymer [18].

In order to examine the relationship between the fiber diameter and volume charge density, a model for the fluid jet inside the electric field has been developed by Fridrikh et al. [19]. The model predicts a terminal jet diameter, which is a result of balance between normal stresses owing to surface charge repulsion and surface tension. It can be found from electrical current, flow rate and the surface tension of the fluid. In another study polyacrylonitrile polymer was used to produce patterned nanofibrous membranes through electro spinning technique [20]. The bulged bubble template was used as collector for manufacturing the patterned membrane. They noted that though the pressure drop reduced in the range of 151.7 to 24.7 mm H_2O, the filtration efficiency reduced only in the range 99.94% to 96.33% when compared to nanofibrous filter [20].

In air filtration applications, reducing the pressure drop and maintaining filtration efficiency play an important role in patterned nanofibers manufacture. The results suggest that electrospinning could be a possible option to produce nanofibrous membranes which can be used in filters to manage hazardous ultrafine particles such as viruses. Electro spun nanofibrous nonwoven mats can be effectively used for the filtration of submicron and nanoparticles for enhanced health protection from different contaminants (e.g. coronavirus). Lackowski et al. [21] reported that these nonwoven mats encompass higher filtration efficiency for nano and submicron particles, which are superior than high efficiency particulate air filters having a filtration efficiency of 99.97% for the particle of size 0.3 micron. The filter created by an electrospinning process is generally charged and due to the presence of electrostatic force it has very high filtration efficiency. The commonly used polymeric materials includes polyvinyl chloride (PVC) and poly vinylidene fluoride (PVDF) [3].

6. Recent developments in face masks

6.1 3D-printed masks

Polypropylene due to its unique features such as easy processability, printability, recyclability, mechanical integrity and low cost, it is normally used for various technical and industrial applications [4, 6]. Alternatively, styrene-(ethylene-butylene)-styrene is a polymeric elastomer which has low processing temperature and low distortion during extrusion. Thus, the combination of polypropylene and styrene-(ethylene-butylene)-styrene can be used for the processability of 3D printed N95 face masks. Furthermore, it could manage the thermoplastic elastomeric ratio tailoring the elasticity and flexibility of the 3D model material to have a fitted face masks. Accordingly, 3D printing procedure is suitable to produce stable and biocompatible N95 masks that are similar to industrial brands [22]. Swennen et al. [23] fabricated a re-usable face mask by employing 3D printing procedure based on the materials and methods (3D imaging and 3D printing). In a 3D protective face mask there are two 3D-printed reusable polyamide composite components (a filter membrane support and a face mask) and two disposable components (filter membrane and head fixation band). The 3D modeling of the masks can be made quickly using computer-aided design. Cai et al. [24] developed a new technology for enhancing the wearing comfort and fit by using a three-dimensional laser scanning method. Acrylonitrile butadiene styrene plastic using the 3D printing method is employed to make the face seal prototypes.

6.2 The nostril filters

The use of nostril filters is an added innovative approach to protect individuals from airborne allergenic particles. The nasal filters located inside the nasal passages are thought to prevent airborne particles coming to the respiratory system. The conventional nasal filters are usually from non-woven web, woven nontoxic mesh, or porous filters. It reduces every day runny nose and sneezing by an average 12% and 45%, respectively [4]. Electrospinning technology enabled nasal filters are more effective in catching nanoparticles before entering into the host and also provides features such as flexibility and minimum pressure drop [25]. Nanofiber nasal filter (NNF) has been prepared by overlaying a carbon filter substrate onto electrospun nylon nanofibers [26]. The filtering efficiency of the filter is more than 90% for particles greater than 1 μm and 50% efficiency for particles less than 0.5 μm. These filters have immense potential in personal protective equipment against exposure to ultrafine particles [4].

6.3 Transparent mask

There is a communication difficulty between the deaf-mute patient and the doctor while wearing a mask. The filter fabric with high optical lucidity can be worn for personal protective equipment while making lip-reading available. On the other hand, there are some challenges in creating a transparent mask and maintaining the filtration efficiency [4]. Electrospinning technology was employed to develop patterned nanofiber air filters with high optical transparency and effective particulate matter 2.5 capture capability [27]. Developed patterned nanofibers showed high particulate matter 2.5 filtration efficiency of 99.99% and high porosity (>80%) with 69% transmittance. Liu et al. developed bilayer electrospun nanofibrous mat from poly (methylmethacrylate) and polydimethylsiloxane. They nonwoven mat showed particulate matter filtration efficiency of over 96% with high optical transmittance 86% [28]. The transparent nanofiber filter is reusable with the ability to retain high particulate matter removal efficiency even after five washing cycles. In a recently study, biodegradable face mask with a hierarchical structure and transparent look has been prepared by printing polylactic acid polymer struts on a polylactic acid nanofiber web by means of electrospinning and 3D printing technology [4, 28]. Hello Mask has been developed by researchers via electrospinning technology [29].

The transparent face mask contains very fine membranes with a pore size of around 100 nanometers, this offers efficient protection against pathogens.

7. Common tests used for respirators and surgical masks

The ASTM standards given by FDA, as the certified standard in the US. Standards ASTM F2100–11 (2011), indicates the performance necessities for the respirators and the face masks. The face masks are classified depending on the performance according to various testing namely breathability, bacterial filtration efficiency, flammability, fluid resistance etc. **Table 4** shows the ASTM F2100–11 levels of protection for face mask selection.

7.1 Bacterial filtration efficiency

Bacterial filtration efficiency (BFE) can be performed as per American society of testing and materials (ASTM) F2101 protocol. This test procedure determines the ability of the face masks to prevent the penetration of microorganisms generated through various activities namely sneezing, coughing and speech. As per this this test standard, the fabric face mask is placed between an aerosol chamber and a six-stage cascade impactor. The aerosol from *Staphylococcus aureus* is fetched into the chamber and using vacuum it is allowed to pass through the mask material. The air flow rate during testing is maintained at 28 L/min. For a minute duration,

ASTM F2100–11 Levels	Resistance to penetration by synthetic blood, minimum pressure in mm Hg for pass result	Differential pressure, mm H20/cm2 (Breathability)	Bacterial filtration efficiency	Sub-micron particulates filtration efficient at 0.1 micron	Flame spread
Level 1: Low barrier protection					
General use for short procedures and exams that do not involve aerosols, spray or fluids	80 mm Hg	< 4.0	≥ 95%	≥ 95%	Class1
Level 2: Moderate barrier protection					
For low to moderate levels of aerosols, spray and/or fluids	120 mm Hg	< 5.0	≥ 98%	≥ 98%	Class1
Level 3: Maximum barrier protection					
For heavy levels of aerosols, spray and/or fluids	160 mm Hg	< 5.0	≥ 98%	≥ 98%	Class1

Table 4.
ASTM F2100–11 levels of protection for face mask selection.

Staphylococcus aureus aerosol is passed to the nebulizer. Subsequently, cascade impactor and the air pressure is allowed to pass through the sample for two minutes. The concentration of the *Staphylococcus aureus* aerosol plays important role, hence it requires to be monitored and may be kept at 2200 ± 500 CFU per test. The mean value of diameter of the bacteria aerosol and the geometric standard deviation must be in the range of 3.0 ± 0.3 μm and 1.5 respectively.

$$BFE = 100\ \frac{(C - F)}{C} \tag{1}$$

where C and F indicates the amount of bacteria colonies present in the control and in the presence of the filter, respectively.

7.2 Particulate filtration efficiency

Particulate filtration efficiency method can be determined as per American society of testing and materials (ASTM) F2299 protocol, and denotes the quality of the surgical masks. The test methods measure the quality of the face masks for filtering the particles with various sizes. According to the FDA regulation certificate, the Particulate filtration efficiency test can be performed using the 0.1 μm polystyrene latex particles. The utilization of latex spheres provides an accurate test for determining a submicron efficiency performance. The polystyrene latex particles have been suspended in water, and the aerosols were produced using the particle generator, which is generally adaptable and can offer the favorable particles concentration. Particle counter downstream can be used to count the particles. The concentration of the aerosol can be attuned from 10,000 to 15,000 particles by feeding through the drying chamber by means of HEPA filtered air. As per the FDA protocols, the used particles are not charge neutralized.

7.3 Viral filtration efficiency

The viral filtration efficiency is normally measured for some face mask such as N95 and N99. In fact this test procedure is similar to ASTM F2101 followed for determining bacterial filtration efficiency. In this method, the bacteriophage ΦX174, contaminates the bacteria namely *Escherichia coli* is utilized as the experiment virus which is aerosolized to produce virus holding water droplets with approximate size of 3:0 ± 0:3 μm. In this method, the agar plates are first inoculated with *Escherichia coli. As a result*, the bacterial cells are lysed to produce plaques and hence parts in contact with the viral droplets become clear. The viral filtration efficiency can be determined by calculating the amount of bacteria colonies present in the control and in the presence of the filter as explained in bacterial filtration efficiency method.

7.4 Fluid resistance

This test method predicts the capability of the masks and respirators to lower the squirted synthetic blood or sprayed fluid which can go through the outer layer of the mask and transmit through the inner part by altering the pressure. As per ASTM F 1862, the penetration resistance capability of the medical face mask is calculated using the high-velocity synthetic blood, which is in contact with the surface layer of the face mask (in a particular time between 0 s and 2.5 s). Some factors such as viscosity polarity, the structure, surface tension, and the relative hydrophobicity or hydrophilicity of the face mask material have shown considerable effect on the penetration and the wetting of the body fluids. By regulating the surface tension of synthetic blood, the wetting properties of blood can be simulated which must be lower than the surface tension range for body fluids, blood excluding saliva approximately in the range of 0.042 Nm^{-1} to 0.060 Nm^{-1}.

7.5 Flame resistance

The hospitals contain various sources of the oxygen, heat, and fuel, the ASTM F2100–11 standards needs an assessment concerning the flame resistance for face masks. The used material for face masks should not contain any hazards for the consumer, and their flammability characteristics should not be high. The sample mask used for the flammability test should not be flamed or remain in flame after five seconds from burning. The flame spread test determines the time required for the flame to reach the sample in 5 inch distance. "Class 1" corresponds to group of the materials, which have standard flame resistance, and they are appropriate for the use in face masks and respirators.

7.6 Differential pressure (Delta-P)

The differential pressure test provides information regarding airflow resistance of the face masks and their breathability characteristics. While performing the test, air passes through the face mask in a controlled way, and different pressures are determined for the inner and outer layers of the face mask. The ratio of differential value to the surface area (cm^2) of the face mask is used to determine the breathability, where high Delta P values denotes a harder breath for the consumers. ΔP can be measured through following relationship.

$\Delta P = PM/4.9$, where PM denotes the mean value of the differential pressure of the face mask, in Pa. As per ASTM F2100–11, the minimum value for Delta P must be lower than 5.0 mm H_2O/cm^2 (or not more than 49 Pa). The Delta P values which are lesser than 0.2 or greater than 0.5 are not considered as standard values for the common surgical use.

8. Conclusions

Wearing a mask is a main factor to retard the spread of the virus. A summary of different types of face masks is discussed in relation to the structure and performance in filtering out the bacteria and viruses. Comparison of properties of nonwoven technology such as melt blown, spun bonding and electro spinning for manufacturing face masks has been discussed. Several researchers are currently making large efforts to innovatively develop 3D-printed respirators, transparent and nostril filters, responding to COVID-19. The progression of advanced masks and respirators will play a critical role in providing protection against COVID-19.

Author details

Thilagavathi Govindharajan* and Viju Subramoniapllai
Department of Textile Technology, PSG College of Technology, Coimbatore, Tamilnadu, India

*Address all correspondence to: thilagapsg@gmail.com

References

[1] Akduman, C., & Akcakoca Kumbasar, E.P. (2018). Nanofibers in face masks and respirators to provide better protection. IOP Conference Series: Materials Science and Engineering, 460,012013.

[2] Rengasamy, S., Shaffer, R., Williams, B., & Smit, S. (2017). A comparison of facemask and respirator filtration test methods. Journal of Occupational and Environmental Hygiene, 14(2), 92-103.

[3] Adanur, S., & Jayswal, A. (2020). Filtration mechanisms and manufacturing methods of face masks: An overview. Journal of Industrial Textiles, doi:10.1177/1528083720980169.

[4] Behera, B. K., & Arora, H. (2009). Surgical Gown: A Critical Review. Journal of Industrial Textiles, DOI: 10.1177/1528083708091251

[5] Derrick, J.L. & Gomersall, C.D. (2005). Protecting healthcare staff from severe acute respiratory syndrome: filtration capacity of multiple surgical masks. Journal of Hospital Infection, 59, 365-368.

[6] Tcharkhtchi, A., Abbasnezhad, N., ZarbiniSeydani, M., Zirak, N., Farzaneh, S., & Shirinbayan, M. (2021). An overview of filtration efficiency through the masks: Mechanisms of theaerosols penetration. Bioactive Materials, 6(1), 106-122.

[7] Rodriguez-Martinez, C. E., Sossa-Briceno, M.P., & Cortes-Luna, J.A. (2020). Decontaminationand reuse of N95 filtering facemask respirators: a systematic review of the literature, American Journal of Infection Control, 48(12), 1520-1522.

[8] Kim, J.H., Wu, T., Powell, J.B., Roberge, R.J. (2016). Physiologic and fit factor profiles ofN95 and P100 filtering facepiece respirators for use in hot, humid environments. American Journal of InfectionControl, 44 (2), 194-198.

[9] W.D. Ungar, T.L. Grimsley, B. Mishkin, Full Face Respirator Mask, Google Patents, 2010.

[10] Scott, R A. (2005). Textiles for protection, Woodhead publishing., Uk., 2005

[11] Madsen, P O., Madsen, R E. (1967) A study of disposable surgical masks, Am. J. Surg. 114(3) 431-435

[12] Konda, A., Prakash, A., Moss, A. (2020) Aerosol filtration efficiency of common fabrics used in respiratory cloth masks, ACS Nano, 14(5), 6339-6345

[13] Soltani, I., & Macosko, C.W. (2018). Influence of rheology and surface properties on morphologyof nano fibers derived from islands-in-the-sea meltblown nonwovens. Polymer, 145, 21-30.

[14] Pu, Y., Zheng, J., Chen, F., Long, Y., Wu, H., Li, Q., Yu, S., Wang, X., & Ning, X. (2018) Preparation of polypropylene micro and nanofibers byElectrostatic-Assisted melt blown and their application. Polymers, 959, 1-12.

[15] Midha, V., & Dakuri, A. (2017) Spun bonding technology and fabric properties: a review. Journal of Textile Engineering FashionTechnology,1, 126-133.

[16] Adanur, S. (1997). Paper machine clothing. USA: Technomic Publishing Co., Inc., 1997.

[17] Meng, K. (2017). Investigation on compound field of electrospinning and melt blowing for producing nanofibers. International Journal of Numerical Methods for Heat & Fluid Flow, 27, 282-286.

[18] Subbiah, T., Bhat G.S., Tock, R.W., Parameswaran, S., & Ramkumar, S.S. (2005). Electrospinning of nanofibers. Journal of AppliedPolymer Science, 96, 557-569.

[19] Fridrikh, S.V., Yu, J.H., Brenner, M. P., & Rutledge, G.C (2003). Controlling the fiber diameter during electrospinning. Physical Review Letter, 90, 144502.1-144502.4.

[20] Lou, L.H., Qin, X.H., & Zhang, H. (2017). Preparation and study of low-resistance polyacrylonitrile nano membranes for gas filtration. Textile ResearchJournal,87, 208-215.

[21] Lackowski, M., Krupa, A., & Jaworek, (2011). A. Nonwoven filtration mat production by electrospinning method. Journal of Physics. Conference Series,301, 1-4.

[22] 22.Ishack, S., & Lipner, S. R. (2020). Applications of 3D printing technology to address COVID 19related supply shortages, American Journal of Medicine, 133(7), 771-773.

[23] Swennen, G.R.,Pottel, L., & Haers, P.E. (2020). Custom-made 3D-printed face masks in case of pandemic crisis situations with a lack of commercially available FFP2/3 masks, International Journal of Oraland Maxillofacial Surgery, 49(5), 673-677.

[24] Cai, M., Li, H., Shen, S., Wang, Y., & Yang, Q. (2018). Customized design and 3D printing of face seal for an N95 filtering facepiece respirator. Journal of Occupational and Environmental Hygiene, 15 (3), 226-234.

[25] Kadam, V.V., Wang, L., &Padhye, R. (2018). Electrospunnanofibre materials to filter air pollutants – A review. Journal of Industrial Textiles, 47(8), 2253-2280.

[26] Han, T.T., Yang, L., Lee, K.B., &Mainelis, G. (2018).Design and Development of a Novel Nanofiber Nasal Filter (NNF) to Improve Respiratory Health. Aerosol and Air Quality Research, 18 (8), 2064-2076.

[27] Cao, J., Cheng, Z., Kang, L., Lin, M., & Han, L. (2020). Patterned nanofiber air filters with high optical transparency, robust mechanical strength, and effective $PM_{2.5}$ capture capability. RSC Advances. 10, 20155 - 20161.

[28] Liu, H., Huang, J., Mao, J., Chen, Z., Chen, G., & Lai, Y. (2019). Transparent Antibacterial Nanofiber Air Filters with Highly Efficient Moisture Resistance for Sustainable Particulate Matter Capture. iScience, 19, 214-223.

[29] G. Fortunato, Hello Mask, 2020. https://www.empa.ch/web/s604/schutzmaske